ENGINEERING CASE LIBRARY

ECL 1-13R

DEVELOPMENT OF AN OIL WELL TUBING STRIPPER RUBBER

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Foreword

This case history is intended for use in teaching engineering design. It consists of two parts:

Mr. Paul E. Bickel's personal narrative shows how he worked as a professional engineer. It was written for this series of case histories to give students an example of the work which a young engineer may do. Working drawings and a view of the device are shown in Appendix A.

The following questions are suggested as examples of problems which may be raised by this case:

At the Freshman level:

What was the problem which Mr. Loudermilk tried to solve? Did Mr. Bickel change the problem statement? Identify and count the iterations in this design. Evaluate Mr. Bickel's formal report. Is it perfectly clear? Perfectly concise? Is anything missing or excessive?

At the Senior level:

What are the criteria for evaluating stripper rubbers? Can you devise a quantitative method of rating competitive stripper rubbers (i.e., a criterion function)? Invent a stripper rubber which will expand as much as the design shown in Figure 1b, but will extrude much less.

Which of Mr. Bickel's decisions was the most important one? Which one was next in importance? What were the rational bases for these decisions?

Many other questions will occur to instructors and students.

This case history is one of a series which is being developed by the Department of Engineering at the University of California, Los Angeles. We gratefully acknowledge the help of the Educational Development Program at UCLA, which supports this work with funds from a Ford Foundation grant, of Paul E. Bickel, of the National Supply Division, Armco Steel Corporation, and of the teachers in the Department.

H. O. Fuchs
January 1964

Personal Narrative

(Not a part of Registration Report)

Designing an Oil Well Stripper Rubber

In 1959 I returned to the Houston plant, National Supply Division, Armco Steel Corporation after having a number of field engineering assignments. At the time of my return I was given the job of a design engineer and in this job was responsible for various projects assigned by my immediate superior, Mr. C. R. Neilon, Chief Engineer of the Houston plant.

I was reassigned to this job in Houston because the product on which I was working as a field engineer was discontinued as a Houston plant product and transferred to another division of the company. This particular product was a reciprocating hydraulic engine which, when coupled to a conventional reciprocating oil well pump, provided an assembly for pumping oil wells with the so-called prime mover down-hole rather than on the surface.

In addition to myself there was another engineer, L. E. Loudermilk, who was reassigned to the Houston plant engineering staff from the Hydraulic Engine Project.

The number of field complaints regarding the existing Type E Stripper Rubber (Exhibit 1) had at that time reached a point where they could no longer be ignored. They had been growing in frequency and intensity for the past 4 or 5 years in direct relation to the greater service requirements demanded by the changing drilling and completion practices of the oil companies. Instead of well pressure conditions of 10 to 100 psi, the conditions were now as severe as 4000 psi. Instead of a requirement to pressure seal with only vertical motion of the tubing string, the requirement now was to seal the tubing string as it rotated. In most cases the Type E design could simply not withstand these service conditions; at best it had a very short life span. Loudermilk was therefore assigned, under the very close supervision of Neilon, to investigate the durability and life characteristics of the Type E Stripper Rubber with the purpose of improving it. This particular product, the Type E Stripper Rubber, was designed by Neilon in about 1950 before he was appointed Chief Engineer. There were no important changes or design modifications of this stripper rubber in the intervening eight or nine years.

Although I was not directly involved in the project at that time, I remember that it was Neilon's feeling that the stripper rubber could be improved and made acceptable by some relatively small changes in dimensions or proportions. Loudermilk and Neilon designed a testing device which incorporated the hydraulic engine with which we were all familiar. This device consisted of a hydraulic engine mounted vertically above a conventional Type E tubing head. Attached to the bottom end of the hydraulic engine piston rod was an adapter containing a female 2 3/8 inch OD tubing thread.

Using the above described testing device the following procedure was established in an attempt to evaluate the stripper rubber. A two foot long piece of tubing was screwed into the engine piston rod adapter. To the bottom of this piece of tubing was screwed a tubing coupling. Below the tubing coupling was screwed another two foot long piece of tubing. The proportions of the test fixture were such that when this tubing assembly reciprocated with the hydraulic engine the tubing coupling would pass through a stripper rubber held in the Type E tubing head. A means for providing a steady stream of cooling water on top of the stripper rubber was incorporated in the test fixture. In addition, it was possible to introduce air pressure into the tubing head beneath the stripper rubber. The reciprocating hydraulic engine was controlled to operate at 25 cycles per minute; that is, 50 passes of the tubing coupling through the stripper rubber each minute, 25 in each direction. Thus the stripper rubbers were tested by measuring the amount of throat seal diameter wear or dimensional increase as a function of time or the number of passes of a tubing collar through the stripper rubber, and also by visually observing air pressure leakage (the degree of bubbling) at the stripper rubber, again as a function of tubing collar passes. For approximately four months Loudermilk tested standard Type E Stripper Rubbers and various shape or configuration changes as well as competitive stripper rubber designs. In all of the tests and design changes that were evaluated, the underlying object was to improve the stripper rubber performance without changing any basic overall dimensions. This was deemed important at that time because any changes would necessitate a complete redesign or new design of the Type E assembly, since the stripper rubber was only one of a number of components, as illustrated on the attached parts sheet (Exhibit 1).

Essentially,the design variables that were evaluated were:

1. Throat seal diameter
2. Throat seal length
3. Thickness of horizontal sections at various points along the entire length of a stripper rubber.

Test models for these various configurations were secured by either machining a standard stripper rubber which was manufactured by compression molding or, when this could not give the desired shape, by producing a part to rough dimensions by mandrel wrapping and then doing final machining.

In a period of approximately four months Loudermilk conducted approximately 50 tests. Of these, approximately ten were standard parts, approximately five were competitive designs, and approximately thirty-rive were modified Type E designs. At this point in the program Loudermilk was transferred from the Houston plant and I was given the responsibility for continuing the effort to improve the stripper rubber design. Before Loudermilk left he wrote an engineering report which summarized the approximately 50 tests he had conducted. One of my first efforts was an attempt to analyze the results of his testing and find some direction in which to proceed. The test result data which he reported and inspection of the models actually tested presented a rather confusing picture. In the final analysis, most of the evaluation of shape modifications which he did had to be discarded because the rubber in many of these models contained small sub-surface voids and folds caused by the rubber molding technique. Subsequent machining of these models would expose these imperfections to the surface where they had a critical effect. The introduction of this variable resulted in radically inconsistent test results. Unfortunately, the significance or importance of these discrepancies was not apparent until near the conclusion of the test program.

In addition, I was not completely satisfied with the reliability of the testing fixture; that is, the reciprocating hydraulic engine device. Primarily, I was concerned with the inability to maintain alignment between the engine and the tubing head which contained the stripper rubber being tested.

For the above reasons it seemed apparent that a completely new approach should be considered. For one thing, outside the considerations of realiability, the testing fixture was quite an awkward mechanism.

All things considered, it would take approximately two days to test one part. I started to wonder if the value of a particular shape could not be determined by the amount of load or pounds of force required to pass a tubing collar through the stripper rubber; the amount of wear should be a function of the amount of force required to pass the collar through the stripper rubber as a result of the seal interference. We had in the plant laboratory a Baldwin tensile testing machine which provided a simple and quick means of measuring the force by direct reading in pounds. At this point I started testing the standard Type E and modifications of the standard Type E design by plotting the load characteristics as shown in a typical plot, Figure 5, page 26. The result of this work was shown on Drawing 516381, Exhibit 2 the section to the left of the center line shows the improved shape, and the section to the right of the center line shows the original shape. I do not have the load characteristics of these two shapes available to me at this time, but as well as I can recall, the load was reduced by approximately 30 percent. I remember that the configuration of the lower containing ring as shown to the right of the center line had a very significant detrimental effect on the load characteristics. I recall that on one test model we removed the lower ring entirely and again reduced the load characteristics significantly. However, for some reason that at this time I do not recall we could not get by without that lower ring. It had something to do with the mating components of the tubing head assembly. At this point, the revised design was tested on the hydraulic engine device and it was concluded that it represented some measure of improvement. However, extrusion tests similar to the test series No. 1 described on page 3 and subsequent field testing of this revised design indicated that it still could not meet the service requirements demanded of it. I felt, however, that it was the best that could be accomplished within the limitations of the basic overall dimensions. Therefore, at this point I wanted to redesign the stripper rubber utilizing the whole tubing head bore ID which meant that the OD of the stripper rubber could be increased approximately 1 1/8 inch. Mr. Neilon did not encourage this approach. At the time I thought the major reason for his objection was pride in his previous work and an unwillingness to accept that it had been outdated. However, Neilon's assistant Mr. W. W. Word, agreed with me that we should attempt to improve the product by major redesign. Therefore, he took the responsibility of encouraging me to work on a redesign without the specific

approval of the Chief Engineer. This, in essence, was the start of the design project documented in the engineering report which follows. All of the early work consisted of making various layouts which incorporated various ideas and experiences accumulated during the program to improve the standard Type E Stripper Rubber design. This work was done for Mr. Work without the knowledge of Mr. Neilon. About the time we were ready to make some parts of this new design Mr. Neilon took a combination business and vacation trip which kept him away from the office for about four weeks. As soon as he left, Mr. Work authorized the expenditure of money to machine molds and manufacture the prototypes of this new stripper rubber design.

By launching a crash program we were able to secure parts in about three weeks. The first load and extrusion tests of the prototype parts were completed before Mr. Neilon returned. The results of these were encouraging enough to inform him of what we had done when he returned. At first he was not enthusiastic but when he considered all of the circumstances at that point he did not object to the project. An illustration of just one of these circumstances is as follows: The highest static pressure carrying capacity of the redesigned standard Type E was something less than 4,000 psi at which point the stripper rubber ruptured; the first prototype of the redesign withstood static pressures in excess of 6,000 psi. So, having gotten approval from Mr. Neilon, it remained only to see the design project to its conclusion.

The bulk of the ensuing work involved modifying the interior and exterior shapes of the stripper rubber as dictated by the load and extrusion tests. In addition, it was discovered that various rubber compounds and rubber durometers had a significant effect on the load and extrusion characteristics. These parameters were altered to give the best combination of characteristics while at the same time attempting to maintain good abrasion characteristics of the rubber compound. We relied entirely on the experience of the rubber compounder to produce good abrasion resistance since this could finally be evaluated only in service.

It was at this point in the design project that the lower metal ring was added to the design as described in Appendix B2 of the report. After completing the above described modifications which were arrived at essentially

empirically by means of load and extrusion tests, it was decided to manufacture a small number of pieces and field test them.

The company's sales department in southern Alabama had complained of losing a considerable number of wellhead sales to competition as a result of the poor performance of the Type E Stripper Rubber. We therefore decided to field test the redesigned stripper rubber in that area. So, with unwarranted enthusiasm, I made a trip to Citronelle, Alabama.

In spite of the fact that I was supposedly bringing a new and much improved product, the sales department was hostile because of the previous problems they had experienced with the old Type E design, and because the Houston plant had been unsympathetic to their problem. The drilling company people were hostile partly by nature and partly because they were of the old school who had drilled millions of feet of oil well without the aid or advice of any young mechanical engineer, whom they suspected did not know the engines from the slush pumps. The natives were hostile because I was obviously a Yankee Carpetbagger uninvited to their rather decrepit and backward community. In this atmosphere I proceeded to supervise the installation and evaluation of the first stripper rubber, of which I was quite proud.

The first one was installed about 2 A. M. and performed satisfactorily for about four or five hours in a rather uneventful test. At this point I went back to my motel for some rest, extremely proud and confident. I returned to the drilling site about noon only to be completely shattered by the sight of my prize stripper rubber lying on the ground almost totally disintegrated. Needless to say, the critical eyes and wise I-told-you-so's were not easy to endure. In fact, careful analysis of the ruined part and descriptions of the circumstances that caused the failure when I was not there caused me to believe that they had deliberately abused the part to insure the failure that was experienced. So, I prevailed on them to try a second part. They agreed to this second test primarily because they were confident it would be no more successful than the first. In fact, the second part failed more rapidly than the first, while I was at the drilling site.

I took the two failed parts and retreated to my motel along with my punctured pride. After regaining my composure and analyzing the failures it became

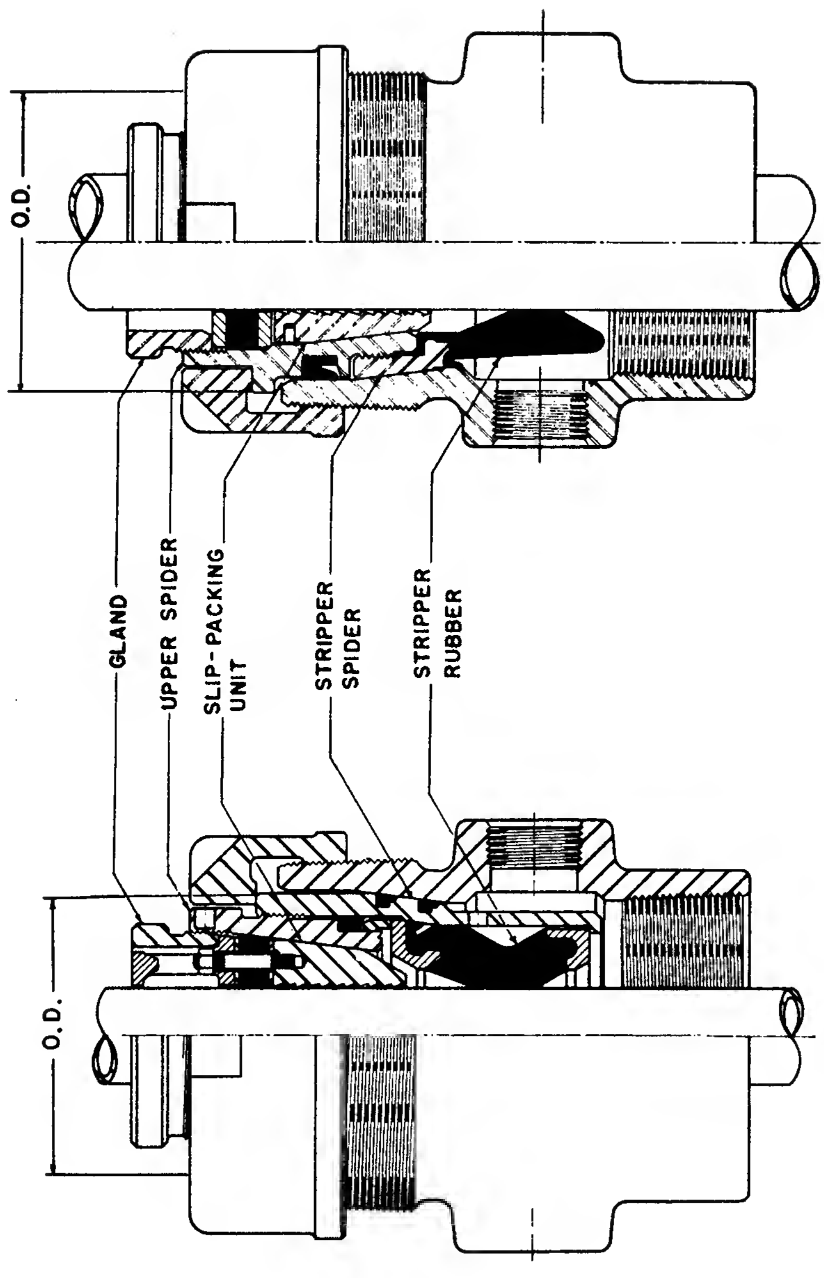
apparent that the main problem was poor bond between the rubber and the top containing ring. I called Houston from Citronelle and discussed this problem with them; we decided to do two things. First, the rubber molder was advised of the difficulty and he in turn indicated to us that the steel rings should have first been coated with an adhesive to insure a good bond. Second, it was deicded to increase the total area of bond between the steel ring and the rubber by adding the circumferential vertical groove shown in Figure 3 and on the working drawings in Appendix A. In addition, the horizontal communicating holes were added to the steel ring to improve the design.

I spent the next two or three days in Citronelle waiting for the Houston plant to ship me some more pieces which incorporated the above described improvements. Needless to say, this was a painful wait. The parts did finally arrive and were placed in service. Fortunately, the performance of these parts was excellent, exceeding not only that of the old Type E design but also that of the best competitive stripper rubbers.

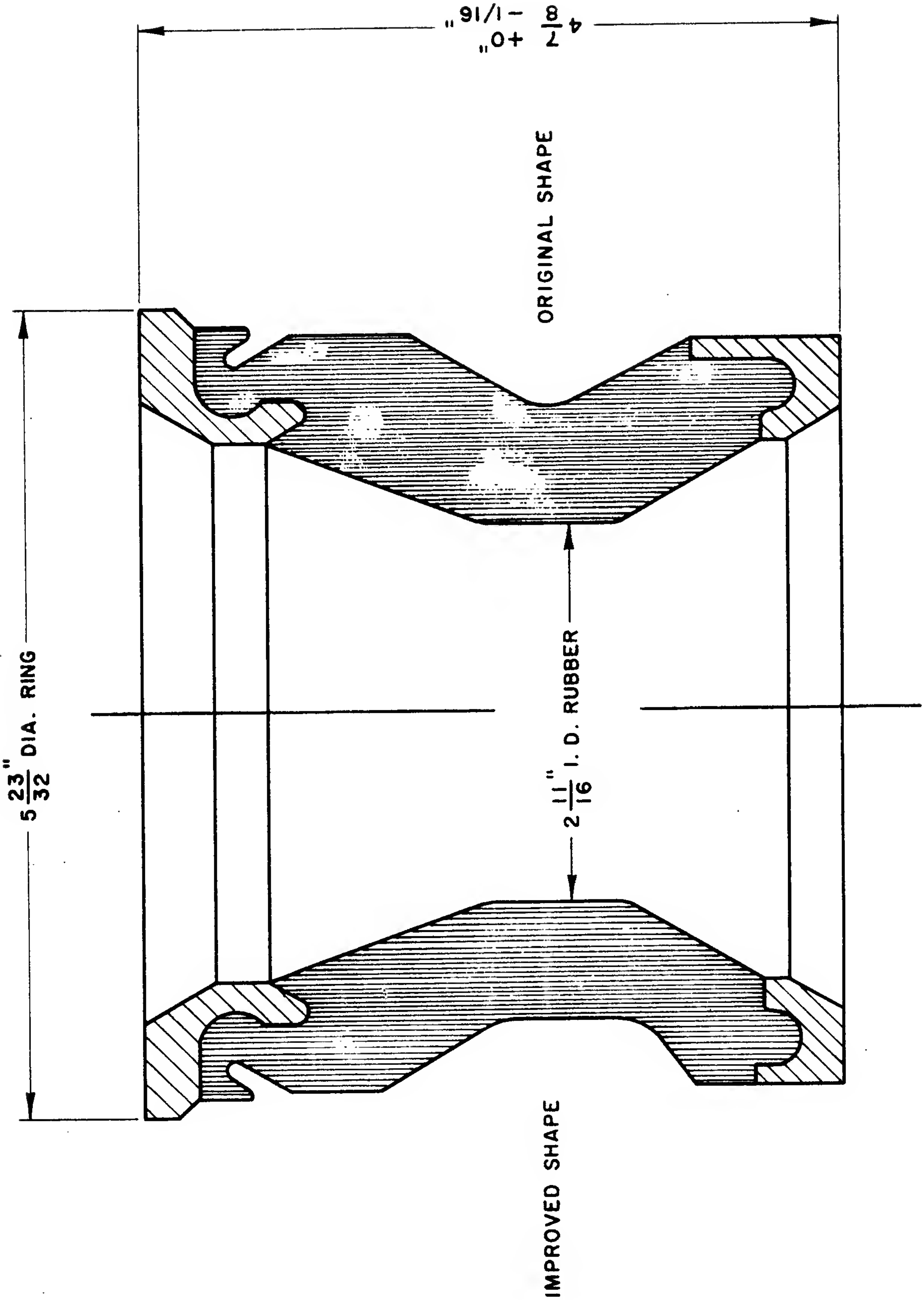
I wasted no time leaving Citronelle, Alabama, with some recovered pride but mainly a good deal wiser. After I returned to Houston another larger lot of prototype parts was produced and distributed to other parts of the country for field evaluation. Again, the field reports of these parts were very successful. The design project was successfully concluded when steel castings of the two insert rings were produced and rubber molds designed to cooperate with these cast rings put into production.

Note: About one year later Mr. Bickel used this job as the basis for a formal report submitted to the Ohio State Board of Registration for Professional Engineers and Surveyors as part of the procedure for registration as a Professional Engineer.

TUBING HANGERS FOR NATIONAL TYPE "E" WELLHEAD EQUIPMENT

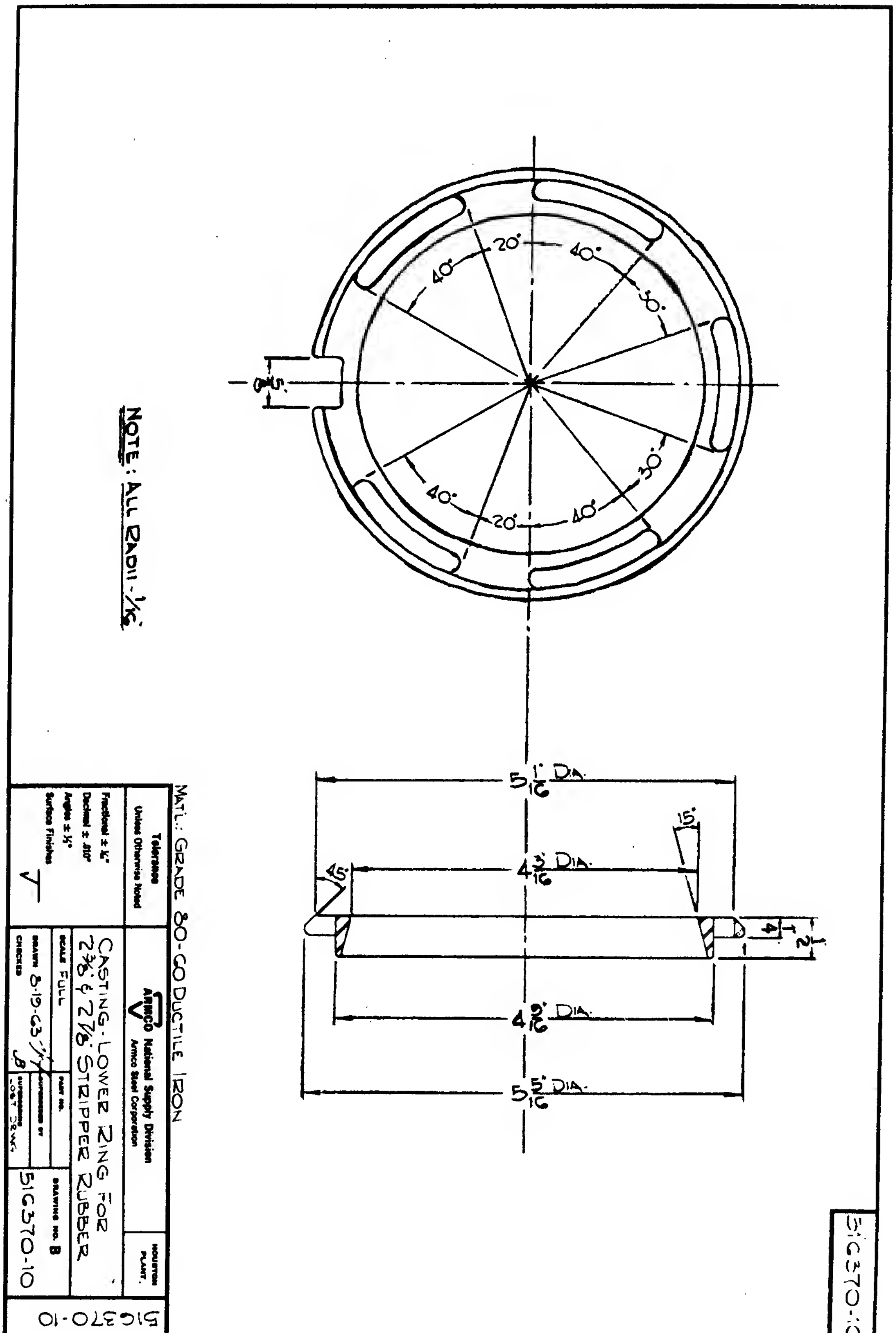


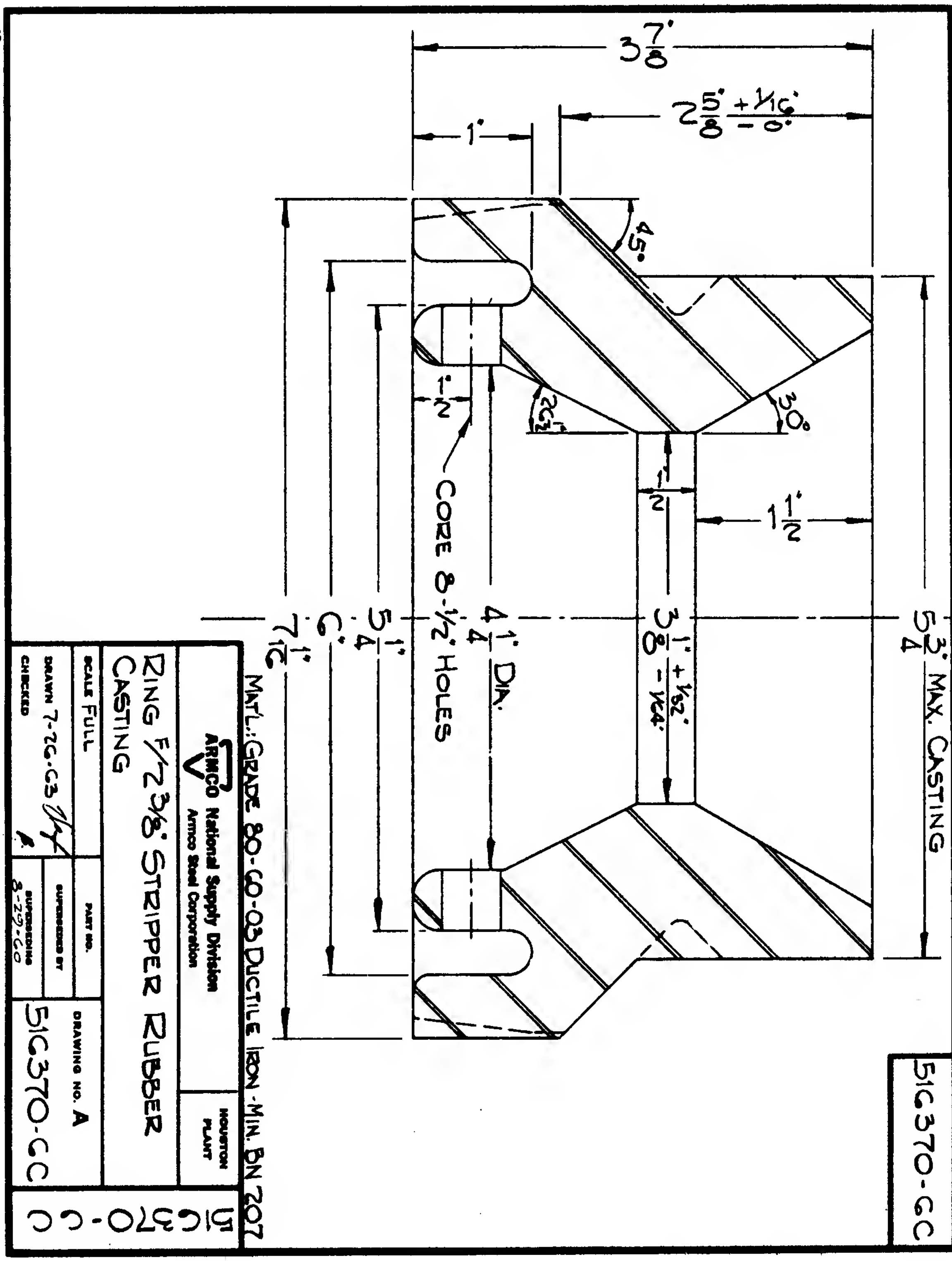
H-3E TUBING HANGER

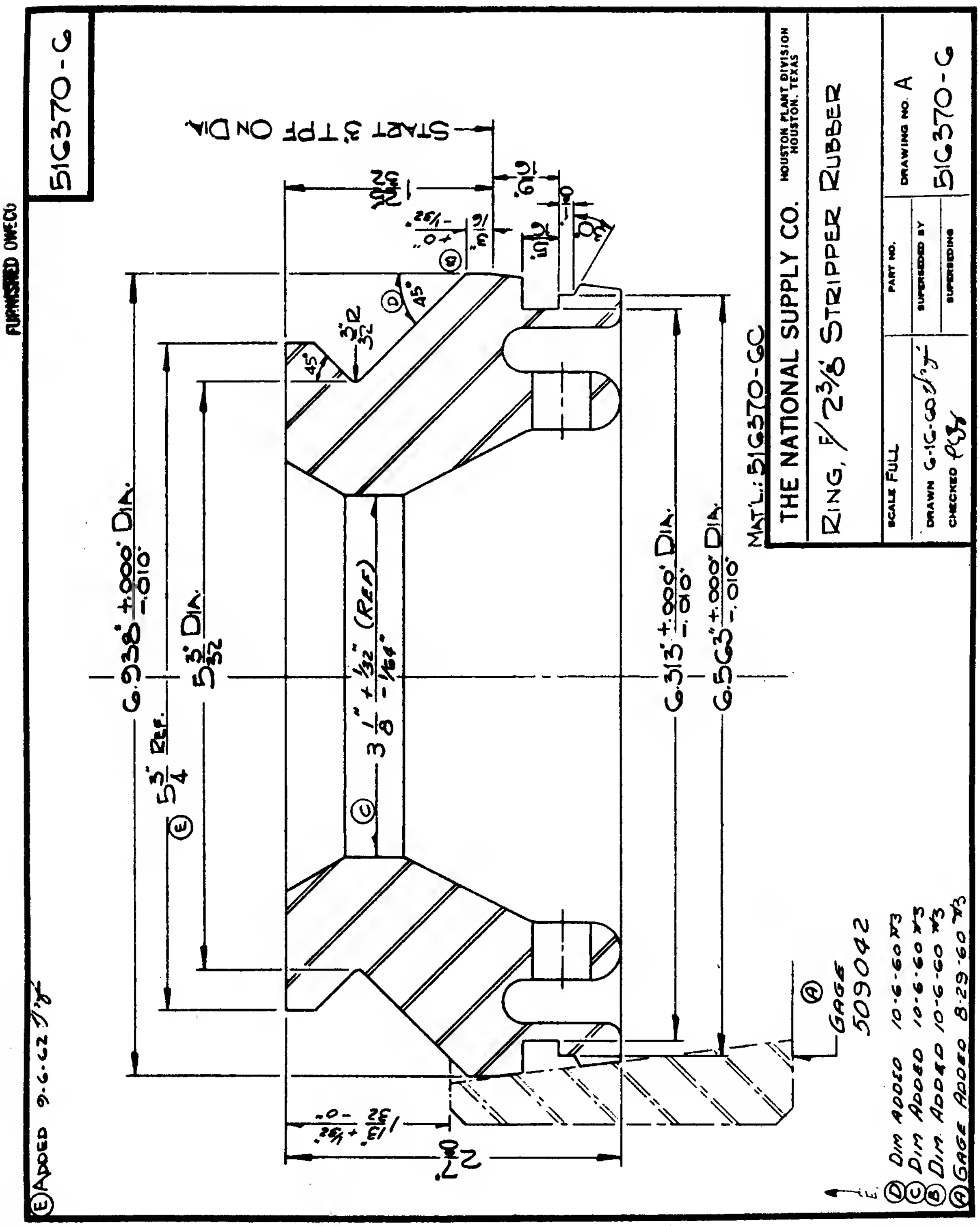

4 7/8 +0" -1/16"
ORIGINAL SHAPE
5 23/32" DIA. RING
2 11/16" I. D. RUBBER
IMPROVED SHAPE

Appendix A

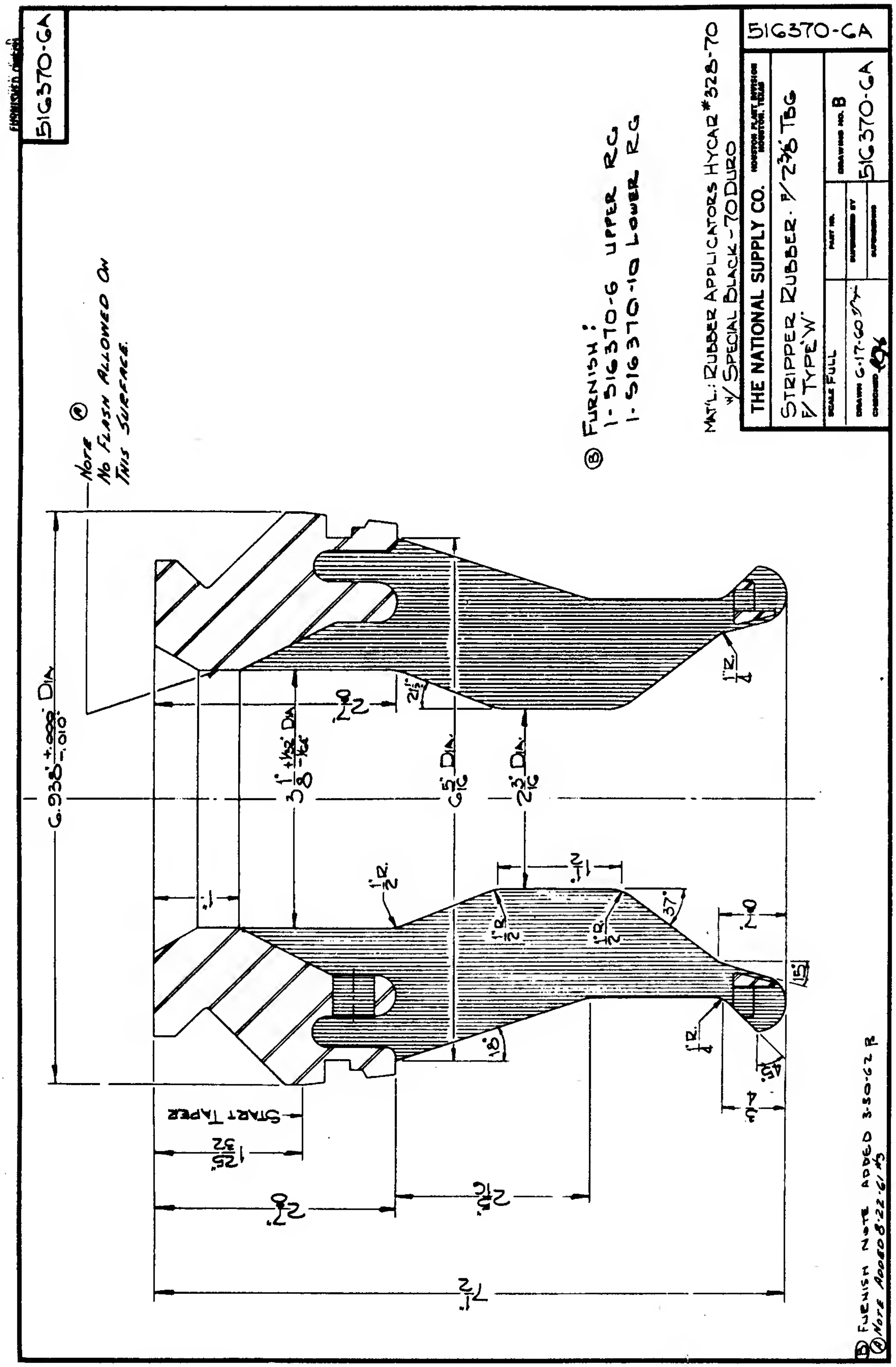
Working Drawings


NOTE: ALL RADII - 1/16
MAT'L: GRADE 80-60 DUCTILE IRON
5 1/16 DIA.
4 3/16 DIA.
4 9/16 DIA.
5 5/16 DIA.
15°
45°
ARMCO National Supply Division
Armco Steel Corporation
CASTING-LOWER RING FOR 2 3/8 & 2 7/8 STRIPPER RUBBER
SCALE FULL
DRAWN 8-19-63
51G370-10


3 7/8"
2 5/8" +1/16" -0"
1"
45°
30°
1/2"
CORE 8-1/2" HOLES
1/2"
1 1/2"
4 1/4" DIA.
3 1/8" +1/32" -1/64"
5 3/4" MAX. CASTING
5 1/4"
6"
7 1/16"
MAT'L: GRADE 80-60-03 DUCTILE IRON - MIN. BN 207
ARMCO National Supply Division
Armco Steel Corporation
HOUSTON PLANT
RING F/2 3/8" STRIPPER RUBBER CASTING
SCALE FULL
DRAWN 7-26-63
CHECKED
PART NO.
SUPERSEDED BY
SUPERSEDING 8-29-60
DRAWING NO. A
51G370-GC
51G370-GC
51G370-GC



THE NATIONAL SUPPLY CO.
HOUSTON PLANT DIVISION
HOUSTON, TEXAS
RING, F/2 3/8" STRIPPER RUBBER
SCALE FULL
DRAWING NO. A
516370-6
MAT'L: 516370-6C
START 3" TPF ON DIA.
6.938" +.000" -.010" DIA.
5 3/32" DIA.
5 3/4" REF.
3 1/8" +1/32" -1/64" (REF)
6.313" +.000" -.010" DIA.
6.563" +.000" -.010" DIA.
GAGE 509042


51G370-GA
NOTE (A)
NO FLASH ALLOWED ON
THIS SURFACE.
(B) FURNISH:
1-51G370-6 UPPER RG.
1-51G370-10 LOWER RG
MAT'L.: RUBBER APPLICATORS HYCAR #328-70
W/ SPECIAL BLACK-70 DURO
THE NATIONAL SUPPLY CO.
STRIPPER RUBBER
TYPE 'W'
SCALE FULL
DRAWING NO. B
START TAPER

The Design and Development of an Oil Well Tubing Stripper Rubber (B)

An Engineering Report
by Paul E. Bickel*

Introduction

The stripper rubber is a component member of the wellhead assembly common to all oil and gas wells. One function of the wellhead equipment is to provide various pressure control means during the drilling, completion, and production of oil and gas wells. This function of wellhead equipment at times requires the use of a stripper rubber. Figures la and lb show the stripper rubber and its placement in a typical wellhead assembly.

The stripper rubber is contained in the body of the assembly immediately below the tubing suspension; it incorporates a pressure seal on the OD; the main body of the rubber is a flexible, resilient material which provides a pressure seal on the OD of the smallest diameter tubular string, generally called tubing.

The function of the stripper rubber lies entirely in this tubing seal. While the stripper rubber is rigidly contained in a body at all times, its twofold functions are, generally speaking, of a static and a dynamic nature. That is to say, the stripper rubber must provide a tubing seal either when the tubing is held stationary or when the tubing is being run into or out of the well. Under static conditions the stripper rubber must be able to contain a maximum fluid or gas pressure of 6000 psi; under dynamic conditions, 200 to 2000 psi.

*National Supply Division
Armco Steel Corporation
Houston, Texas

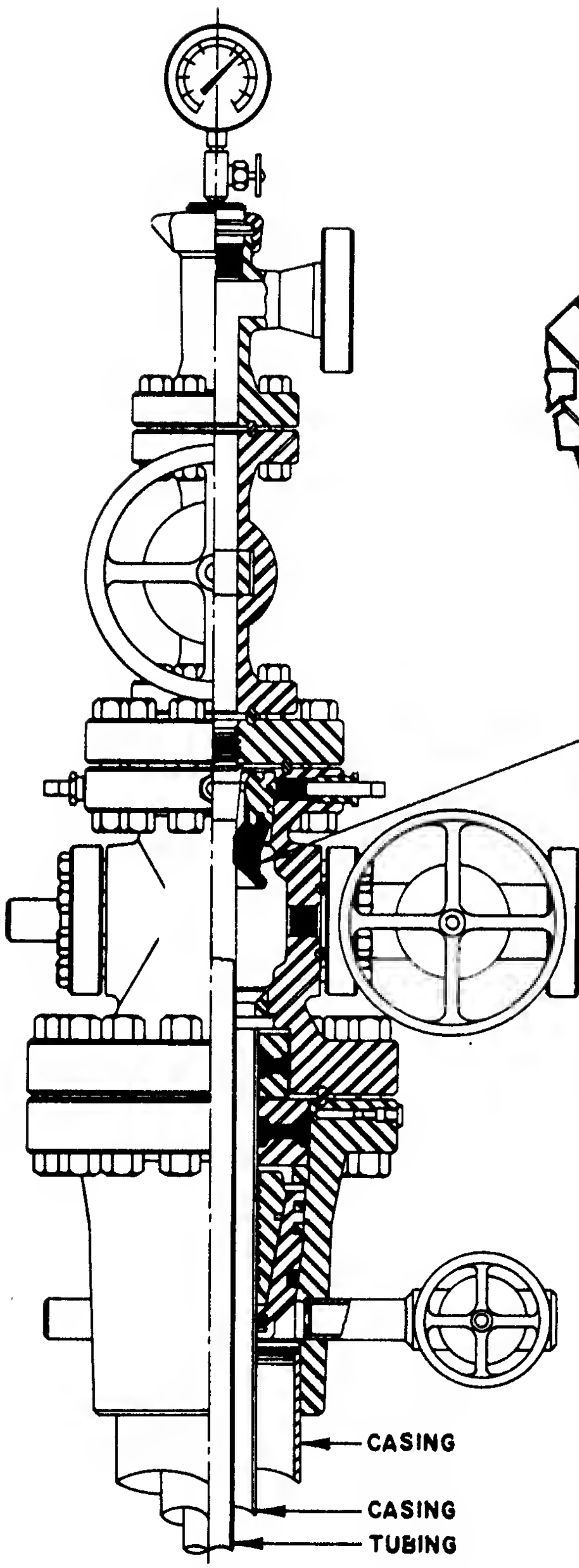


Figure 1a

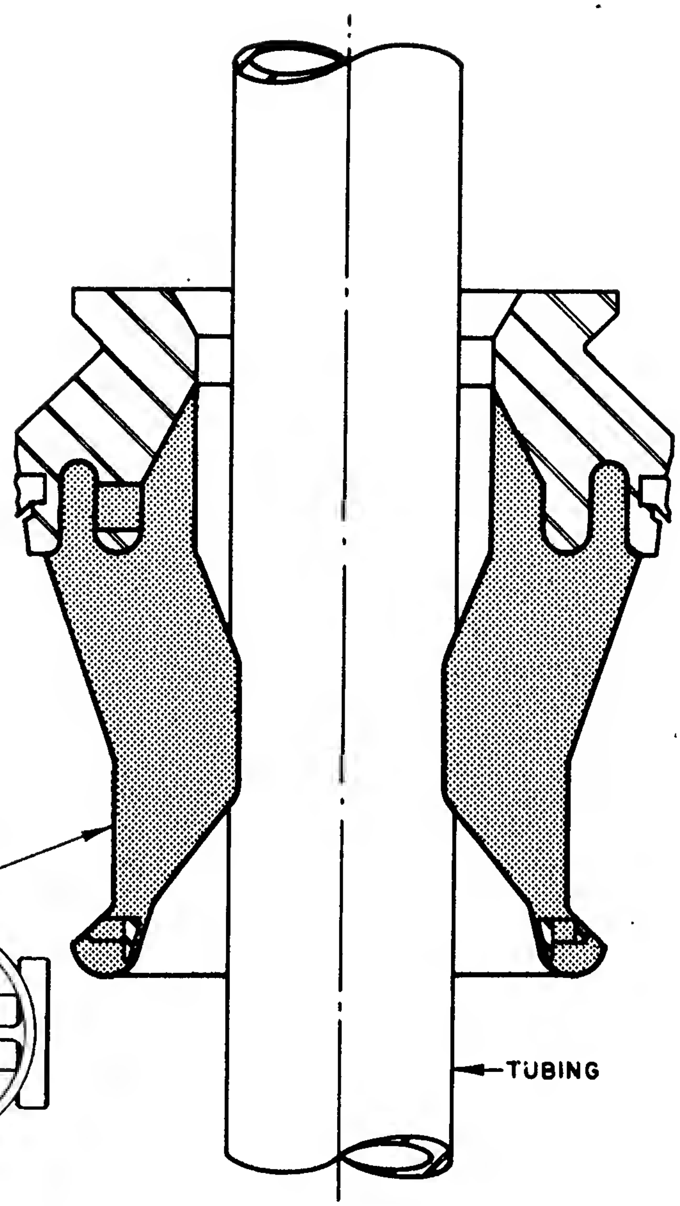


Figure 1b

The Problem

The principal design problem and the condition which distinguishes this seal design from other common mechanical seals is the considerable variance in diameter that each size stripper rubber must seal. For example, in the common 2 3/8" and 2 7/8" tubing sizes, the coupling diameters are 3 1/16" and 3 43/64" respectively. This represents a minimum to maximum diameter difference of 11/16" and 51/64"; that is, the stripper rubber must seal on the smallest diameter and still be able to pass and seal a diameter 11/16" or 51/64" larger. See Figure 2.

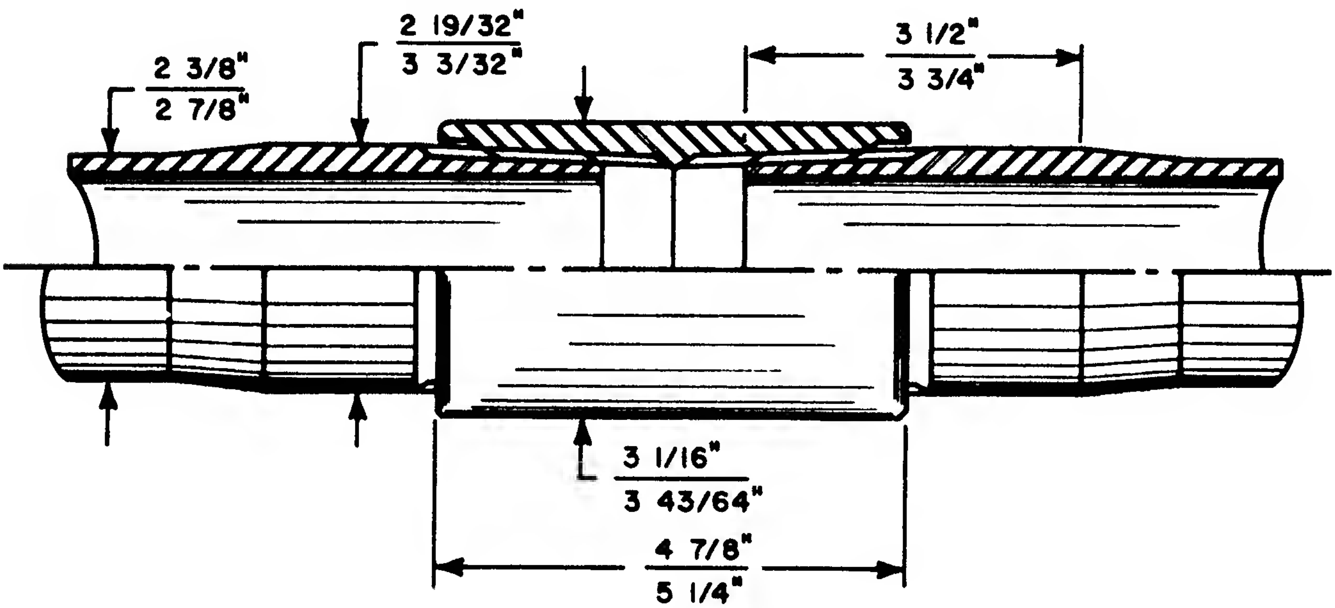


FIGURE 2

To arrive at the optimum shape, two considerations were of prime importance. First, the physical dimensions of the design should be such that rubber extrusion or flow under pressure will be as small as possible consistent with the design conditions.* Second, the amount of force required to pass the tubing through the rubber will be as small as possible consistent with the other conditions. This second premise is based on the theory that the force required to pass tubing through the rubber is a significant influence on the amount of service wear due to friction between the stripper and the tubing.

*Extrusion is illustrated in Figure 3.

The physical properties of the rubber compound will have an important influence on both of the above considerations. Later in this report it will be explained how the compound was varied to meet the desired conditions.

Design Procedure

In order to proceed systematically, various portions of the stripper rubber were considered separately and in the following order:

1. Throat seal length and diameter
2. Containing ring
3. Horizontal sections
4. Rubber material specifications

The two sizes under consideration were 2 3/8" and 2 7/8". Preliminary investigation and consideration revealed that the 2 7/8" size was more critical for the following reason:

Area of Φ, 3 43/64"	diameter =	10.59 in.^{2}
Area of Φ, 2 7/8"	diameter =	6.49 in.^{2}
	Difference =	4.1 in.^{2}

Area of Φ, 3 1/16"	diameter =	7.37 in.^{2}
Area of Φ, 2 3/8"	diameter =	4.43 in.^{2}
	Difference =	2.94 in.^{2}

$$\frac{4.1^{\circ\prime\prime} - 2.94^{\circ\prime\prime}}{2.94^{\circ\prime\prime}} \times 100 = 39\%$$

That is, assuming the same throat seal length, the volume of rubber to be displaced in passing a 2 7/8" coupling is 39% more than the volume of rubber to be displaced in passing a 2 3/8" coupling; and the load required is obviously a direct function of the volume of displaced rubber. Also, the seal diameter variance is 7/64" greater in the 2 7/8" size.

The throat seal diameter can be expressed in terms of nominal tubing size interference; that is, 3/16" interference on diameter in a 2 7/8" stripper rubber gives a throat seal diameter equal to 2 11/16". Since the frictional resistance force and consequently service life or wear is a direct function of the throat seal interference and the throat seal length, it was

suspected that some optimum dimension for these two quantities did exist. On the other hand, it was obvious that these quantities (optimum) are essentially empirical in nature because of the large number of influencing factors. Loudermilk* conducted an investigation of these dimensions and concluded the following:

Optimum throat seal diameter interference - 3/16"

Optimum throat seal length - 1 1/2"

His results indicated that more interference or greater seal length did not appreciably increase wear life due to an increasing rate of wear.

The containing ring at the top of the stripper rubber is primarily a foundation piece and guide bushing. It serves as a base to which the rubber form can be molded. The OD configuration of this ring is determined by the configuration of the bowl which carries the stripper rubber in service. The bore of the ring and the shape where it is bonded to the rubber had to be determined. The necessary bore is a function of the maximum diameter the stripper rubber must be able to pass. It is important to have the minimum possible bore in order to minimize the seal gap which the rubber must bridge when sealing on the minimum diameter. The other interior shape of the ring was chosen to provide adequate bond area. The circumferential vertical groove provides for maximum rubber bond area. The initial field tests indicated a need for the horizontal communicating holes to increase the mechanical bond strength between the rubber and the ring.

The interior and exterior shape of the rubber, or the horizontal sections, were arrived at as a result of the following considerations:

1. Sufficient rubber section in the area of the containing ring to provide adequate tensile strength and minimize rubber extrusion under pressure. (Appendix B1)

2. A rubber section in the area of the containing ring that will allow maximum flexure of the lower section of the stripper rubber. (Appendix B1)

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*L. E. Loudermilk, "Engineering Report", The National Supply Company, Houston, Texas, July 15, 1959.

(Note: A condition of compromise was necessary to satisfy the conflict between 1 and 2.)

3. Entrance tapers to the throat seal area in order to provide reasonably smooth passage of the irregular diameter tubing string.

4. A structural insert at the lower end to reduce rubber extrusion at high pressures. The value of this was determined by tests that are detailed in Appendix B2.

The requirements of the rubber compound are a series of contradicting physical properties as follows:

1. High modulus in order to minimize extrusion
2. Low modulus to provide ease of passing the irregular diameters
3. High ultimate tensile strength
4. Good abrasive and tear resistance
5. Low compression set properties
6. High resistance to hydrocarbon attack

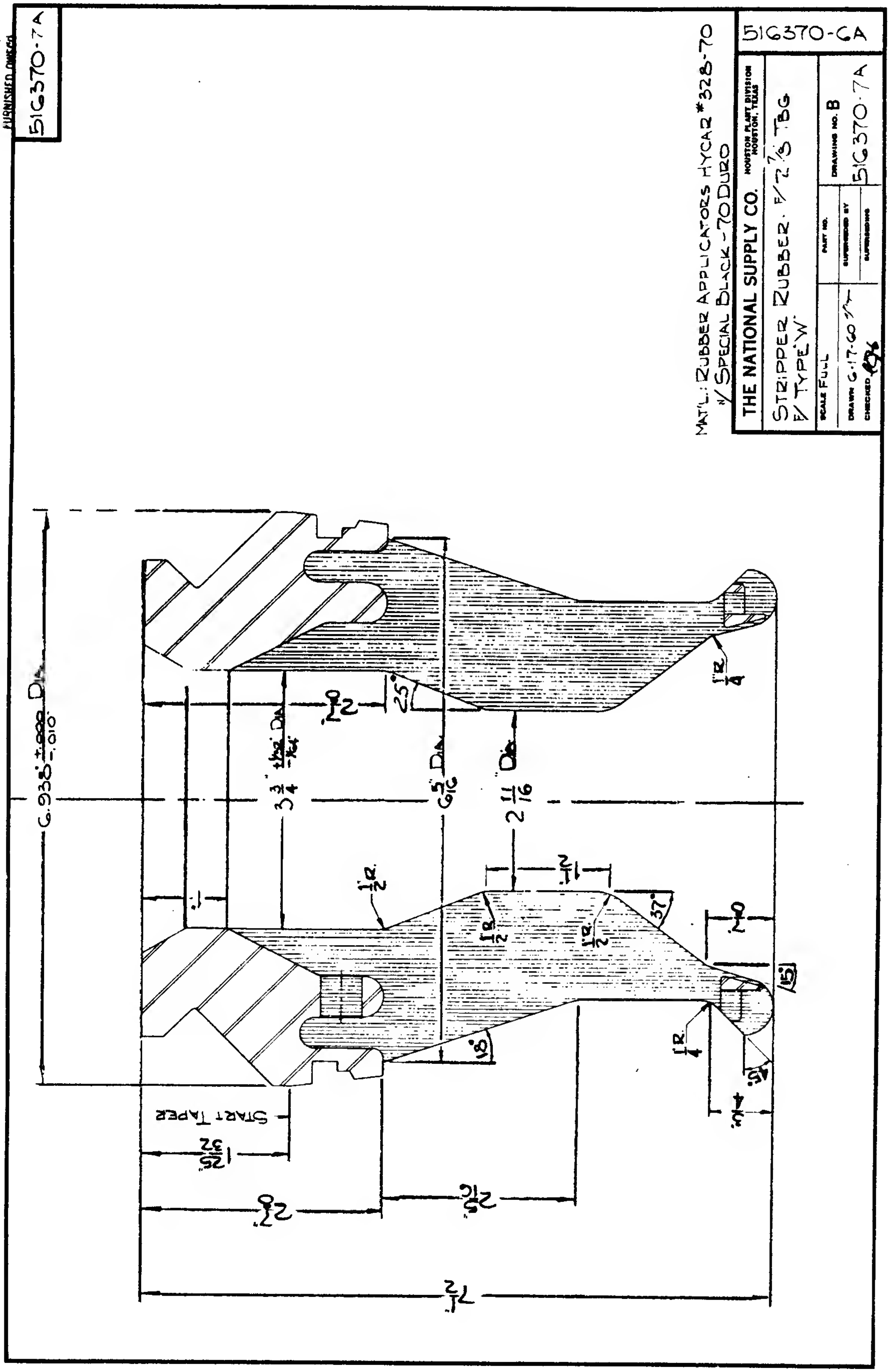
Details of the rubber compound were developed in conjunction with the molded-rubber vendor in the following manner. Initially a compound was chosen which represented some compromise of each of the physical properties required. This was tested to determine the weakest property. The compound was then altered to strengthen the weak point, retested, altered again, retested, etc. As an example, tests revealed one sample to have poor abrasive resistant property. The rubber compound was changed to use a much finer carbon black ingredient. The result was much improved abrasive resistance, with little sacrifice of the other desired properties.

The nature of the tests outlined above was twofold. The rubber molder conducted various tests in accordance with ASTM Standard D735-52. Final refinement of the rubber compound was accomplished by conducting field service tests to evaluate the service wear life. Due to the wide range of service conditions and the inability to secure identical field conditions, the results of these tests were only relative for any set of conditions, but each test by itself served as a general guide in arriving at the final rubber compound.

Conclusion

The drawing, 516370-7A (Exhibit B-1) dated June 16, 1960 is the design resulting from the work outlined in this report. Field service reports on the use of this product indicate that remarkable durability and long service life have been achieved.

Final Design



Final Design

Appendix B-1

Two series of tests were conducted to determine the optimum shape as outlined on page 18.

Test series #1:

This series of tests consisted of measuring the vertical extrusion in the seal gap. The test setup and measurements are shown in Figure 3.

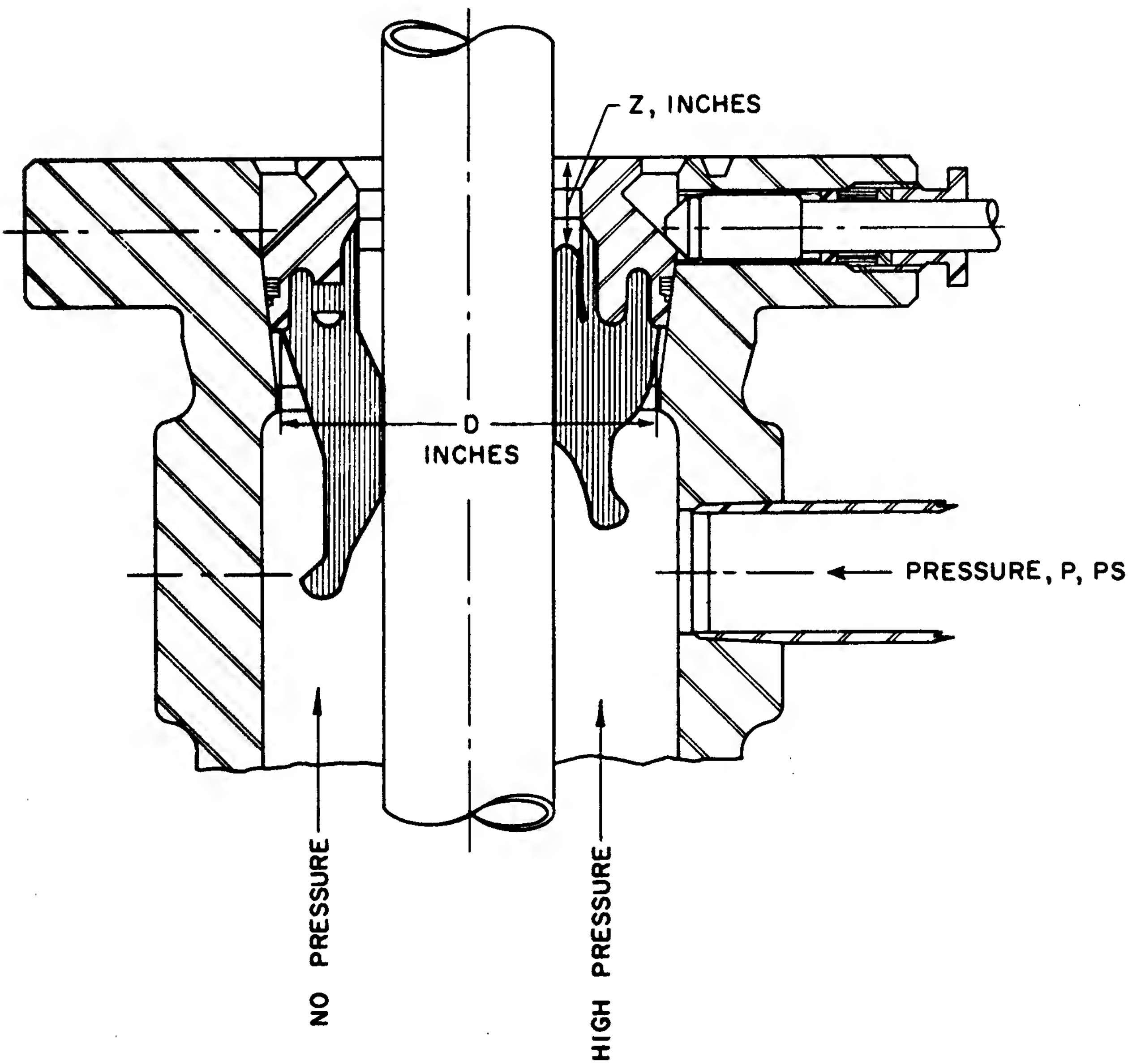


FIGURE 3

Test series #2:

This series of tests consisted of measuring the load required to pass a collar through the stripper rubber. The test setup shown in Figure 4 was arranged in a Baldwin-Southwark Universal Testing Machine where the collar penetration in inches and the applied load in pounds were taken as direct readings. A typical plot of these readings is shown in Figure 5.

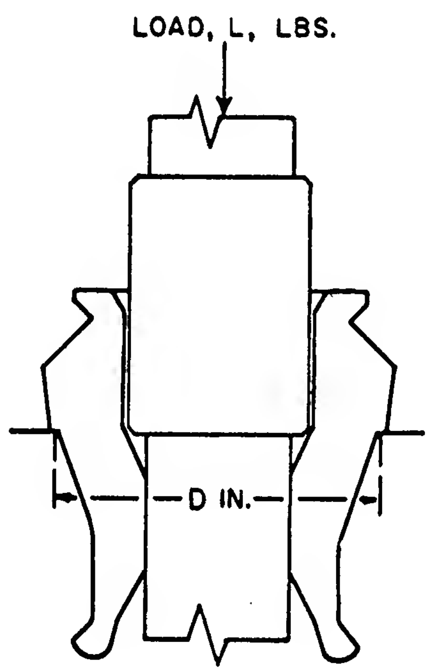


FIGURE 4

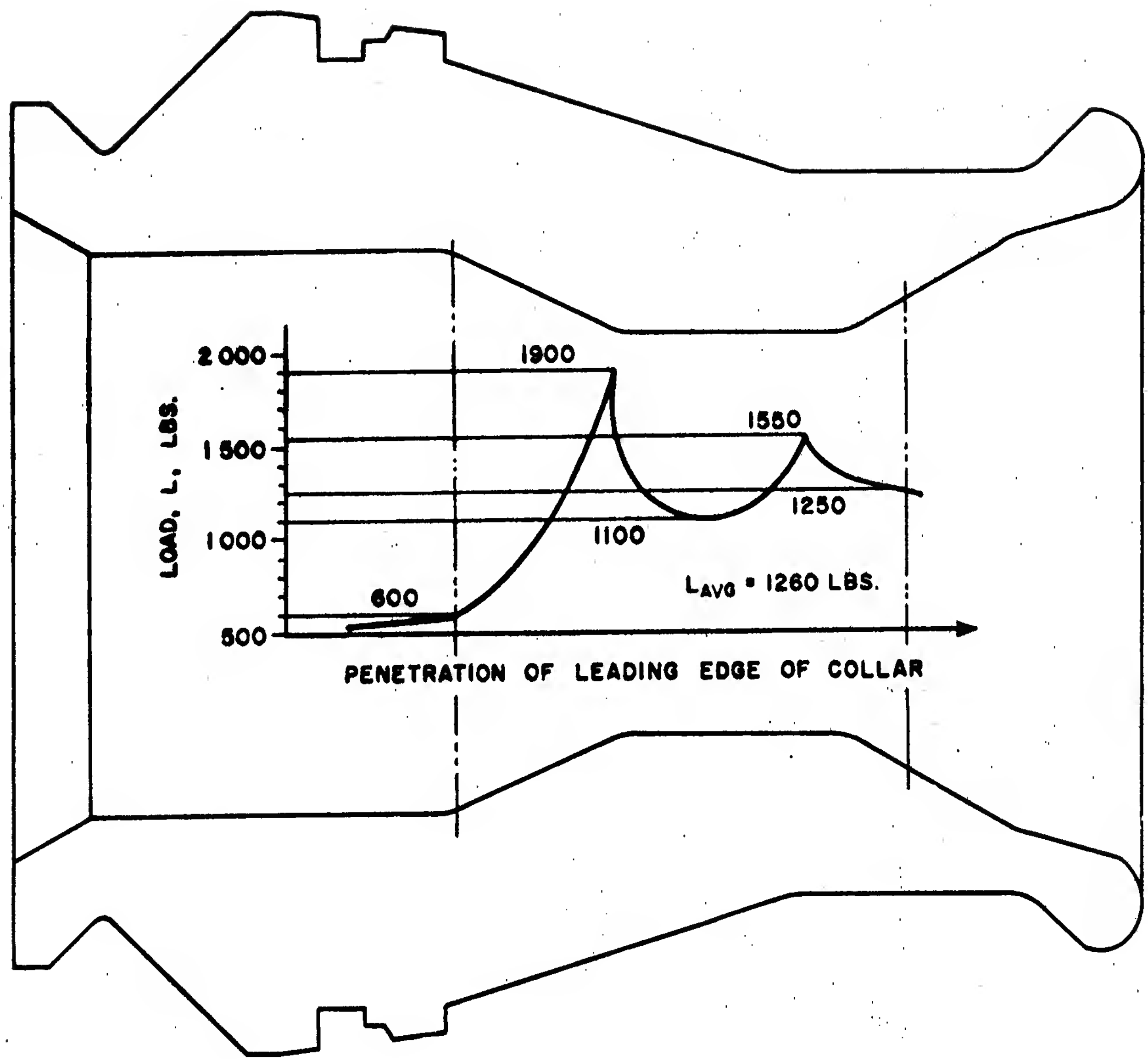

2 000
1 500
1 000
500
LOAD, L, LBS.
1900
1550
1250
1100
600
L_{AVG} = 1260 LBS.
PENETRATION OF LEADING EDGE OF COLLAR

FIGURE 5

Test Results

Series #1 and #2

Table I

D* Inches	Series #1		Series #2
	P psi	Z** Inches	L Avg. Lbs.
5 7/8"	3000 6000	1 1/8" 7/8"	1165
6 5/16"	3000 6000	1 3/8" 1 3/16"	1300
6 1/2"	3000 6000	1 7/16" 1 5/16"	1740

Table II

D, inches		Reduction of Extrusion	% Increase Load
5 7/8"	6 5/16"	36%	12%
6 5/16"	6 1/2"	19%	34%

Conclusion

In comparing the two increment increases in D, it became apparent that the D = 6 5/16" was the more desirable since the lesser reduction of extrusion at 6 1/2" was at the expense of considerable load increase.

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*See Figure 4 for definition of Z

**See Figure 3 for definition of D

Appendix B-2

Test series #3:

The first prototype stripper rubber that was built did not contain the metal ring in the lower lip. In a test setup the same as outlined in Appendix B-1, Test series #1, this stripper rubber was pressured to 8100 psi at which pressure the bottom lip completely inverted (see Figure 6). Although 8100 psi is considerably above the maximum required working pressure, the test did point out the need to investigate the effect of a ring in the bottom.

The test setups were the same as Test series #1 and #2, Figures 3 and 4.

<u>Results:</u>

Stripper Rubber	Extrusion			Load	
	P psi	Z inches	% Reduction	L* Ave. Lbs.	% Increase
Without Lower Ring	3000 6000 8100	1 3/8" 1 3/16" Failure	—	1040	—
With Lower Ring	3000 6000 10000	2 1/16" 1 7/8" 1"	50% 58% -	1440	38%

Conclusion

The addition of the lower ring resulted in much improved extrusion characteristics of the rubber. The load increase was also significant but tolerable.

*See Figures 7 and 8 for load curves.

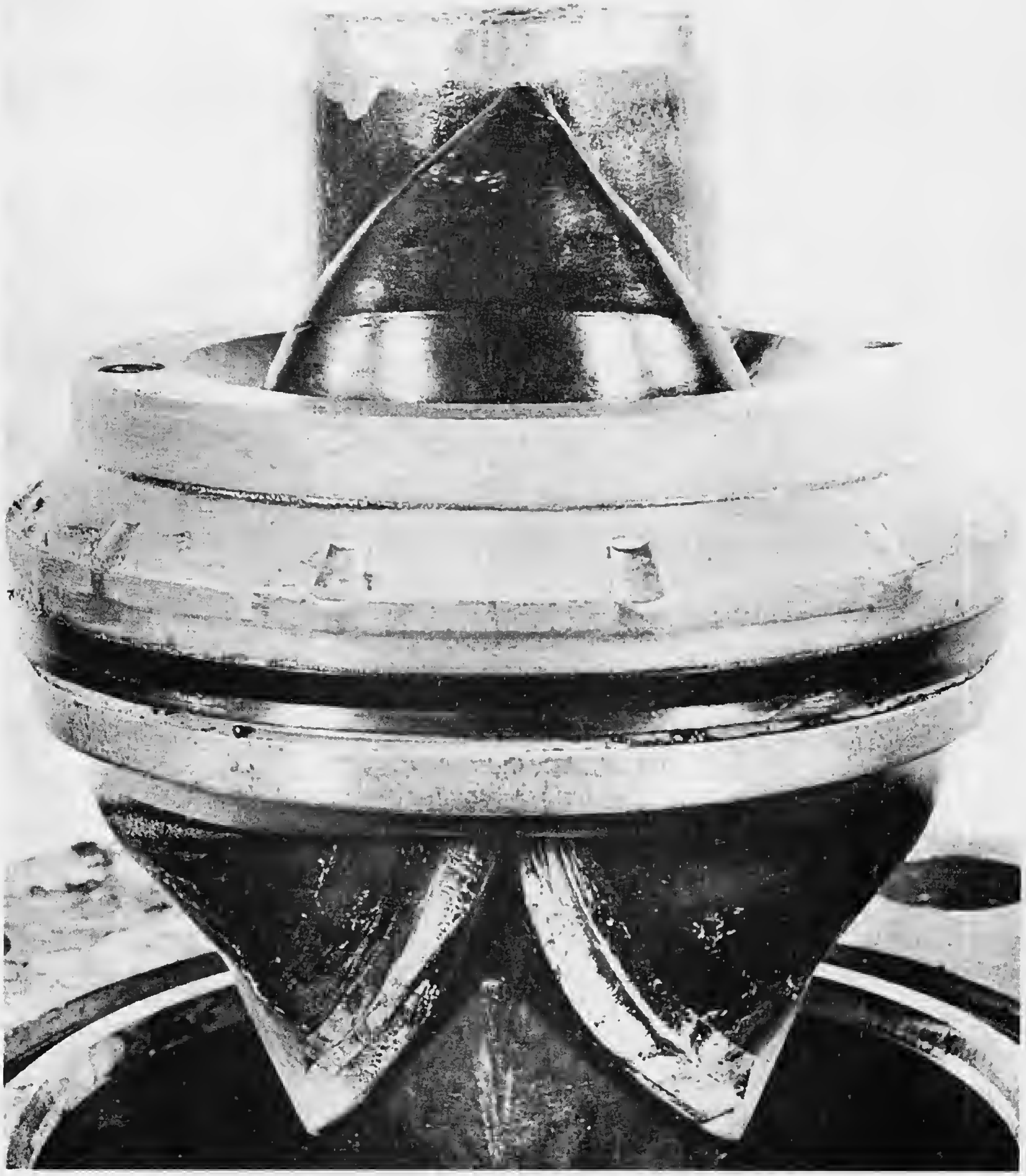
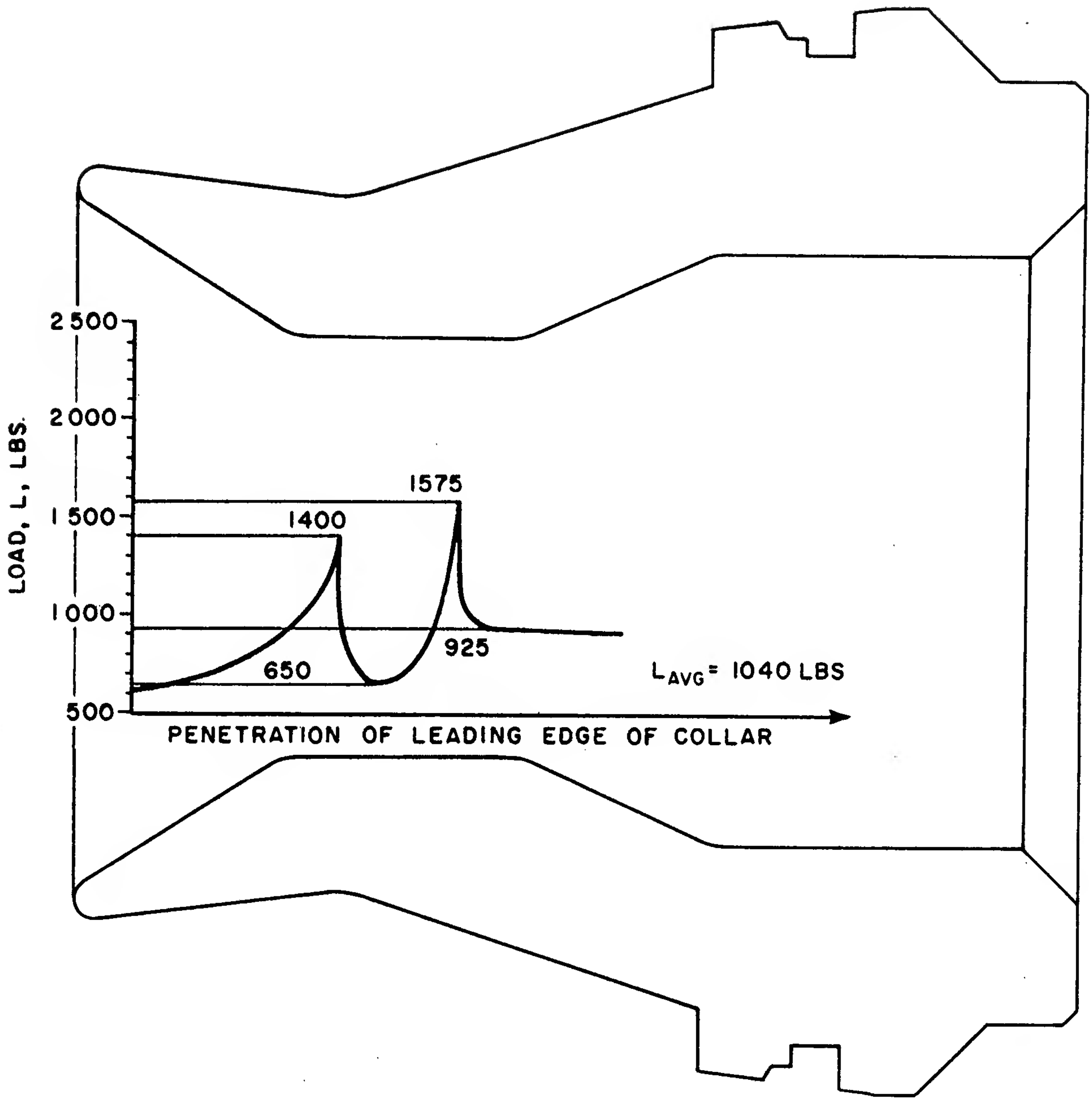


FIGURE 6



2500
2000
1500
1000
500
LOAD, L, LBS.
1575
1400
925
650
L_{AVG} = 1040 LBS
PENETRATION OF LEADING EDGE OF COLLAR

FIGURE 7

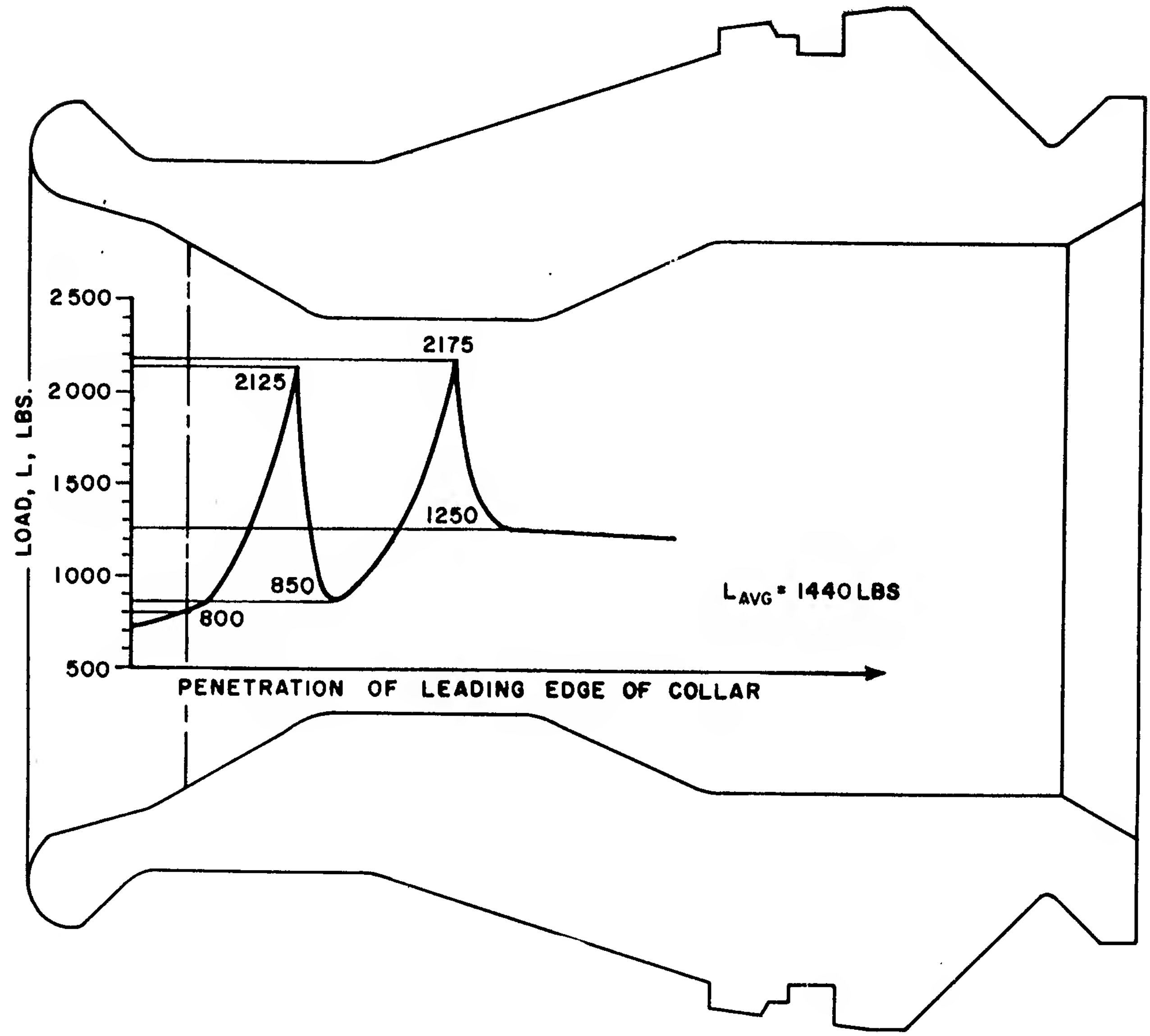

2500
2000
1500
1000
500
LOAD, L, LBS.
2175
2125
1250
850
800
L_{AVG} = 1440 LBS
PENETRATION OF LEADING EDGE OF COLLAR

FIGURE 8